

Appendix D

Datums and Reference Systems

D.1 Datums

Before the advent of manmade satellites, geodetic positions in surveying were determined separately, either horizontally in two-dimensions as latitudes and longitudes or vertically in the third dimension as heights or depths.

Horizontal datums, using a reference ellipsoid, an origin, and an azimuth orientation, were defined to relate surveyed horizontal positions to each other into one common local, regional, continental, or national system. All horizontal datums have been defined using geodetic data only over land areas. Examples are Old Hawaii Datum, Tokyo Datum, North American Datum 1927, or Indian Datum. These horizontal datums remained non-geocentric in definition; the largest shift from the geocenter determined so far is about two kilometers.

Vertical datums, using a Mean Sea Level (MSL) surface as an approximation to the geoid, were defined to relate surveyed vertical positions, orthometric heights or elevations, to each other in one common regional, continental, or national system. In case of ocean areas, the depths, or bathymetric data, from one region to another are defined with respect to various tidal surfaces, e.g., Mean Lower Low Water (MLLW), Lowest Astronomic Tide (LAT). Examples are Baltic or North American Vertical Datum (NAVD) 1988.

D.2 Geodetic Reference Systems

Using the satellites orbiting around the Earth, the determination of geodetic positions became three-dimensional, either as rectangular (X, Y, Z) coordinates or converted to geodetic (latitude, longitude, ellipsoidal height) coordinates using an Earth-centered ellipsoid.

The ellipsoidal heights are geometric heights, above or below the ellipsoid; they can be related to the orthometric heights by using geoidal undulations or heights. For a true

geocentric geoid, the geoidal heights may vary from about 100 meters, below or above the reference ellipsoidal surface.

Examples are the World Geodetic System (WGS) 1984, or European Reference Frame (EUREF) 1989, or South American International Geodetic Reference System (SIRGAS) 1995. Recently, these geodetic systems have also been realized nationally, e.g., Korea Geodetic System (KGS) 1995. The International Terrestrial Reference Frame (ITRF) does not constitute by itself a geodetic reference system.

The geodetic reference system used by GPS is the WGS 84 (Ref. 12). The details of the models, the parameters, their uncertainties, and relationships to other systems are given in the reference. The WGS 84 reference frame and the most recent ITRF systems are in agreement to better than two centimeters.

D.3 Geoid

The geoid is a specified equipotential surface, defined in the Earth's gravity field, which is used as zero reference for orthometric heights or elevations. Historically, due to a lack of gravity data to accurately model this reference surface, vertical datums have been defined with respect to MSL even though MSL is not an equipotential surface and has a slope.

For aviation and other applications with stringent vertical accuracy requirements, an accurate, global geoid is needed to convert ellipsoidal height information from GPS determinations to orthometric heights. As a by-product of a 3-year joint project involving NASA and NIMA to determine an improved spherical harmonic model of the Earth's gravitational potential, a globally defined, high accuracy WGS 84 geoid (Ref. 12) has been produced.

Now, orthometric heights or elevations can be realized using GPS-surveyed geocentric ellipsoidal heights and the WGS 84 geoid with consistent zero definition all over the world.

D.4 Land Maps

Most of the maps over land are based on old classical datums (D.1 above). It is only with the availability of NAD 83 and WGS 84 (or its predecessor WGS 72) that horizontal topographic features/details on maps have been produced in the geocentric datums.

All vertical features and elevations on land maps are still referenced to MSL as zero reference.

D.5 Nautical Charts

Until very recently, nautical charts were surveyed on land-based horizontal datums that were extrapolated or extended to cover the adjoining ocean areas.

In 1983, International Hydrographic Organization (IHO) designated the use of the World Geodetic System as the universal datum. Since then, the horizontal features have been

based on WGS 84 or in the case of U.S. charts on NAD 83, which is geodetically compatible with WGS 84.

All vertical features and depths are still defined with respect to tidal surfaces, which may differ in definition from chart to chart.

D.6 Aeronautical Charts

Until very recently, aeronautical charts were surveyed on land horizontal datums that were extended to cover the adjoining airspace overhead.

In 1989, International Civil Aviation Organization (ICAO) designated the use of the WGS 84 for all aerodromes as the universal datum. Since then, the conversion surveys have been in progress.

For horizontal features, the surveys will be based on WGS 84 or in geodetic reference systems that are geodetically compatible to it. All vertical features and elevations will be determined with respect to the WGS 84 geoid to achieve global consistency.

D.7 Map and Chart Accuracies

When comparing positions derived from GPS with positions taken from maps or charts, an understanding of factors affecting the accuracy of maps and charts is important.

Several factors are directly related to the scale of the product. Map or chart production requires the application of certain mapmaking standards to the process. Because production errors are evaluated with respect to the grid of the map, the evaluation represents relative accuracy of a single feature rather than feature-to-feature relative accuracy. This is the “specified map or chart accuracy.” Another factor is the symbolization of features. This creates an error in position because of physical characteristics, e.g., what distance is represented by the width of a line symbolizing a feature. In other words, what is the dimension of the smallest object that can be portrayed true to scale and location on a map or chart. Also, a limiting factor on accuracy is the map or chart user’s inability to accurately scale the map coordinates given by the grid or to plot a position.

Cartographic presentation or “cartographic license” is also an error source. When attempting to display two or more significant features very close together on a map or chart, the cartographer may displace one feature slightly for best presentation or clarity.

Errors in the underlying survey data of features depicted on the map or chart will also affect accuracy. For example, some hazards on nautical charts have not always been accurately surveyed and hence are incorrectly positioned on the chart.

As a final cautionary note, realize that maps and charts have been produced on a variety of datums. The coordinates for a point in one datum will not necessarily match the coordinates from another datum for that same point. Ignoring the datum shift and not applying the appropriate datum transformation can result in significant error. This applies whether one is comparing the coordinates of a point on two different maps or charts or

comparing the coordinates of a point from a GPS receiver with the coordinates from a map or chart.

D.8 Electronic Chart Display Information System (ECDIS)

The Electronic Chart Display Information System (ECDIS) has emerged as a promising navigation aid that will result in significant improvements to maritime safety and commerce. More than simply a graphics display, ECDIS is a real-time geographic information system (GIS) that combines both spatial and textual data into a readily useful operational tool. As an automated decision aid that is capable of continuously determining a vessel's position in relation to land, charted objects, aids to navigation, and unseen hazards, ECDIS represents an entirely new approach to maritime navigation and piloting. It is expected that ECDIS will eventually replace the need to carry paper charts.

The development of an international performance standard for ECDIS was finalized by the International Maritime Organization (IMO) in May 1994. The IMO Performance Standards for ECDIS were formally adopted by the Nineteenth Assembly of IMO on November 23, 1995. To ensure early dissemination, IMO issued ECDIS Performance Standards as MCS/Circ. 637 on May 27, 1994.

As specified in the IMO Performance Standards, the primary function of ECDIS is to contribute to safe navigation. ECDIS must be capable of displaying all chart information necessary for safe and efficient navigation organized by, and distributed on the authority of, government-authorized hydrographic offices. With adequate backup arrangements, ECDIS may be accepted as complying with the up-to-date charts required by regulation V/20 of the Safety-of-Life-at-Sea (SOLAS) Convention of 1974. In operation, ECDIS should reduce the navigation workload compared to using the paper chart. It should enable the mariner to execute in a convenient and timely manner all route planning, route monitoring, and positioning currently performed on paper charts. ECDIS should also facilitate simple and reliable updating of the electronic navigation chart. Similar to the requirements for shipborne radio equipment forming a part of the global maritime distress and safety system (GMDSS), and for electronic navigation aids, ECDIS onboard a SOLAS vessel should be in compliance with the IMO Performance Standard.

For the electronic navigation positioning system to be used with an IMO-compliant ECDIS, it is specified that:

- The vessel's position be derived from a continuous positioning system of an accuracy consistent with the requirements of safe navigation.
- A second independent positioning method of a different type should be provided; and, ECDIS should be capable of detecting discrepancies between the primary and secondary positioning systems.
- ECDIS provide an indication when the input from a positioning system is lost or malfunctioning.

When ECDIS and radar/Automatic Radar Plotting Aid (ARPA) are superimposed on a single display, they provide a system that can be used both for navigation and collision

avoidance. As specified in the IMO Performance Standards, radar information may be added to the ECDIS display, as long as it does not degrade the display and is clearly distinguishable from the electronic navigation chart. The IMO Performance Standard further stipulates that both the ECDIS and radar use a common reference system (e.g., WGS 84), and that the chart and radar image match in scale and orientation.